Intelligent Infrastructure:
A Primer

WHITE PAPER

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Contents

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Preface

Kiva Allgood
Managing Director and Head, Centre for Advanced Manufacturing and Supply Chains

Roberto Bocca
Head, Centre for Energy and Materials

Akshay Joshi
Head, Centre for Cybersecurity

Jeff Merritt
Head, Centre for Urban Transformation

Infrastructure has always been the foundation of economic progress. In the industrial era, nations that built physical infrastructure such as roads, railways, water and power grids gained enduring competitive advantages. Today, a comparable and perhaps more consequential transition is underway through intelligent infrastructure. The question is no longer simply how well a country builds and connects physical assets, but how intelligently those assets can sense, communicate, learn and act.

Intelligent infrastructure is not merely a technology investment. It is a determinant of national competitiveness. The ability to embed systems-level intelligence and autonomy into the systems that power economies will increasingly separate those that lead from those that follow.

Intelligent infrastructure is inherently cross-sectoral. Its implications span industrial production, energy systems, urban services, supply chains and national security. As such, it requires coordinated action across policy, investment and governance. Our aim is to help policy-makers and business leaders with the frameworks and evidence to navigate this transition as a structural systems-wide transformation rather than an isolated technology shift.

This report, developed with global leaders across industries, presents the DNA+ framework – a practical architecture that makes the concept of intelligent infrastructure concrete. Grounded on real-world experience from four diverse expert communities, spanning advanced manufacturing and supply chains, energy and materials, cybersecurity and urban transformation, the framework maps the systemic outcomes of intelligent infrastructure across four levels: Company, Cluster, City and Country. It further offers deployment pathways to translate potential into systemic value.

The infrastructure choices made today will shape economic outcomes for decades. Governments, businesses and international partners are invited to engage with this work – to implement, test and refine the framework, contribute market feedback and participate in structured collaboration. Intelligent infrastructure is not a destination but an evolving capability: one whose strategic value will compound over time and whose development requires coordination across public and private sector actors. The Forum stands ready to serve as a neutral platform for collaboration, supporting policy-makers and businesses as they shape the intelligent backbone of long-term competitiveness.

Executive summary

Intelligent infrastructure enables physical infrastructure to sense, reason and act in real time by integrating sensing devices, network connectivity, AI and cyber resilience.

Just as roads and ports enabled the movement of goods in the industrial age, intelligent infrastructure enables the flow of intelligence in the intelligent age. Intelligent infrastructure integrates physical assets with sensors, connectivity, data platforms, artificial intelligence (AI) and feedback loops into coordinated systems ("system of systems") that can sense, reason and act in real time. These features make it fundamentally distinct from traditional digital infrastructure, which limits itself to foundational connectivity and data exchange.

1. **DNA+ framework as a blueprint.** This report introduces the DNA+ framework as a practical architecture for building intelligent infrastructure. Three layers form its core, with an additional cross-cutting cyber resilience layer. Together, these layers enable cognitive outcomes: agentic operations, cognitive assets, hyper-adaptive services and symbiotic ecosystems:

   D **D**evices that interact with the physical world to capture real-time data.

   N **N**etwork that provides secure, high-speed connectivity for data to flow across organizational and sectoral boundaries.

   A **A**rtificial intelligence spanning the full stack from data platforms and analytical models through to AI orchestration to govern the intelligence that coordinates the system-of-systems approach.

   \+ Cyber resilience, which functions as a cross-cutting layer, embedded throughout by design rather than appended after deployment.

2. **Impact across 4Cs.** Intelligent infrastructure generates value across the 4Cs (Company, Cluster, City, Country) creating reinforcing, multiplying effects. Transformation in one reinforces performance at all levels: company transformation strengthens cluster capabilities; cluster infrastructure and city transformation amplify national competitiveness; and national frameworks enable all.

3. **Technology is ready for deployment, but the enabling conditions are not.** Four deployment imperatives determine whether technology's potential translates into systemic value:

   – Governance frameworks must be built, including interoperability standards, accountability mechanisms, data governance policies and regulatory environments that enable controlled experimentation.

   – Trust must be established, through neutral convening bodies, transparent benefit-sharing mechanisms that enable participants to see returns proportional to their data contributions, and participation models designed to be accessible to organizations of all sizes, ensuring smaller enterprises are not excluded by high entry requirements.

   – Public and private capital must play complementary roles, with public investment in foundational layers serving a catalytic function that crowds in private capital.

   – Capacity-building must be domain-specific and operationally embedded, including cluster-level training platforms that give small and medium-sized enterprises (SMEs) access to skills they could not develop independently.

Intelligent infrastructure is an evolving national capability that will bring strategic advantage to the nations that act now. The choices made today will shape economic performance, sustainability outcomes and industrial relevance for decades to come.

Introduction

As humanity transitions into the intelligent age, the foundations of social and economic competitiveness are undergoing a fundamental shift.

> Investing in intelligent infrastructure is not merely a technology upgrade, but a strategic imperative for economic resilience and growth in the intelligent age.

Just as the steam engine and railways defined the first industrial revolution and the internet defined the information age, the emerging intelligent age[1] demands a new foundation: intelligent infrastructure. The World Economic Forum's report *Beyond Cost: Country Readiness for the Future of Manufacturing and Supply Chains*[2] identifies intelligent infrastructure as one of the critical factors determining national competitiveness to drive foreign industrial investments.

In previous eras, nations that modernized their physical infrastructure by building ports, railways or stable power grids were the first to gain enduring economic advantages. Today, a similar but more profound shift is underway. The competitive frontier has moved beyond physical infrastructure alone to the ability to embed intelligence into these systems that power economies. This is what intelligent infrastructure enables. It creates a dynamic, data-driven backbone that is no longer a passive connector of goods or data, but an active participant in value creation, enabling real-time, adaptive optimization and autonomous decision-making where feasible and appropriate. It supports cross-industry collaboration through shared standards and data ecosystems, while enabling resource sharing and sustainable development through intelligent resource optimization.

This report aims to provide policy-makers and business leaders with a foundational overview of intelligent infrastructure, outlining what it is and why it matters. Drawing on global best practices, implementation lessons and community insights*, the report highlights that investing in intelligent infrastructure is not merely a technology upgrade, but a strategic imperative for economic resilience and growth in the intelligent age.

Leading economies are already proving this thesis. The People's Republic of China has invested strategically in intelligent infrastructure through the deployment of interoperability standards, industrial networks and cross-industry data platforms. By developing the "Industrial Internet", China's smart manufacturing sector is projected to attain a market size of approximately $127 billion by 2030.[3] Similarly, India is redefining its economic competitiveness through its unified logistics interface platform (ULIP). By integrating real-time data from 33 distinct systems – spanning customs, railways and ports – into a single intelligent backbone, India aims to reduce its logistics costs from 14% to below 10% of GDP, significantly boosting the global competitiveness of its manufacturing exports.[4]

The evidence is compelling: nations that invest strategically in intelligent infrastructure today will define the economic landscape of tomorrow. Those that delay risk being left behind in an increasingly intelligent, interconnected and adaptive global economy.

BOX 1

Industrial internet

Industrial internet refers to the integration of industrial machinery, sensors, control systems and software with advanced connectivity, cloud computing and AI to monitor, optimize and automate industrial operations in real time.

It connects physical assets – such as factories, power plants, ports and transport systems – to digital platforms, enabling predictive maintenance, operational efficiency, improved safety and data-driven decision-making across industrial value chains.

The term is often used interchangeably with the industrial internet of things (IIoT), although it typically emphasizes large-scale industrial systems and enterprise-level integration rather than individual connected devices.

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*Community insights were derived from six in-person workshops, conducted globally by the World Economic Forum in 2025, and from one-to-one consultations with 15+ multistakeholder experts.

1

What is intelligent infrastructure?

Intelligent infrastructure integrates physical and digital infrastructure into adaptive, data-driven systems capable of sensing, learning and acting in real time.

1.1 Understanding intelligent infrastructure

The term "intelligent infrastructure" is used with growing frequency by governments, industry leaders and technology developers alike, yet its meaning is rarely made precise. It is sometimes conflated with digital infrastructure or sometimes reduced to the deployment of sensors or AI applications. These framings capture fragments of intelligent infrastructure yet miss the essential character of a unified, intelligent system.

BOX 2

Intelligent infrastructure – a definition

Intelligent infrastructure can be defined as the integrated system of physical assets, communications networks, digital platforms and AI that enables infrastructure to develop cognitive capabilities – the ability to sense, connect, learn and act in real time, serving as the foundational backbone of competitiveness in the intelligent age.

While physical infrastructure, such as roads, power grids, factories and ports, forms the material backbone of economic activity and digital infrastructure provides the connectivity layer for data exchange, intelligent infrastructure goes further: it integrates these layers into adaptive, data-driven systems capable of sensing, learning and acting in real time. The result is infrastructure that does not merely report what is happening, but reasons for itself, dynamically optimizing energy flows, pre-empting equipment failures, re-routing logistics or traffic and enabling cross-sector coordination at scale.

It is this systems-level intelligence – the ability to sense, reason, optimize and act across interconnected assets and actors simultaneously – that distinguishes intelligent infrastructure and defines its value. Such systems-wide integration enables what might be termed "system-of-systems visibility": consolidated platforms that aggregate data across companies, sectors and utilities, resulting in higher productivity for companies, more sustainable cities and industrial clusters* and stronger national competitiveness.

India's Smart Cities Mission exemplifies this approach, having operationalized integrated command and control centres (ICCCs) across 100 cities that consolidate data from traffic management, public safety, utilities and environmental monitoring onto unified platforms, enabling real-time, cross-departmental decision-making at both municipal and national scales.[5]

*Industrial clusters are geographical areas where co-located companies and other institutions operate in close proximity. The Transitioning Industrial Clusters initiative led by the World Economic Forum is a coalition of global industrial clusters committed to economic growth, employment and decarbonization.

1.2 How intelligent infrastructure differs from digital infrastructure

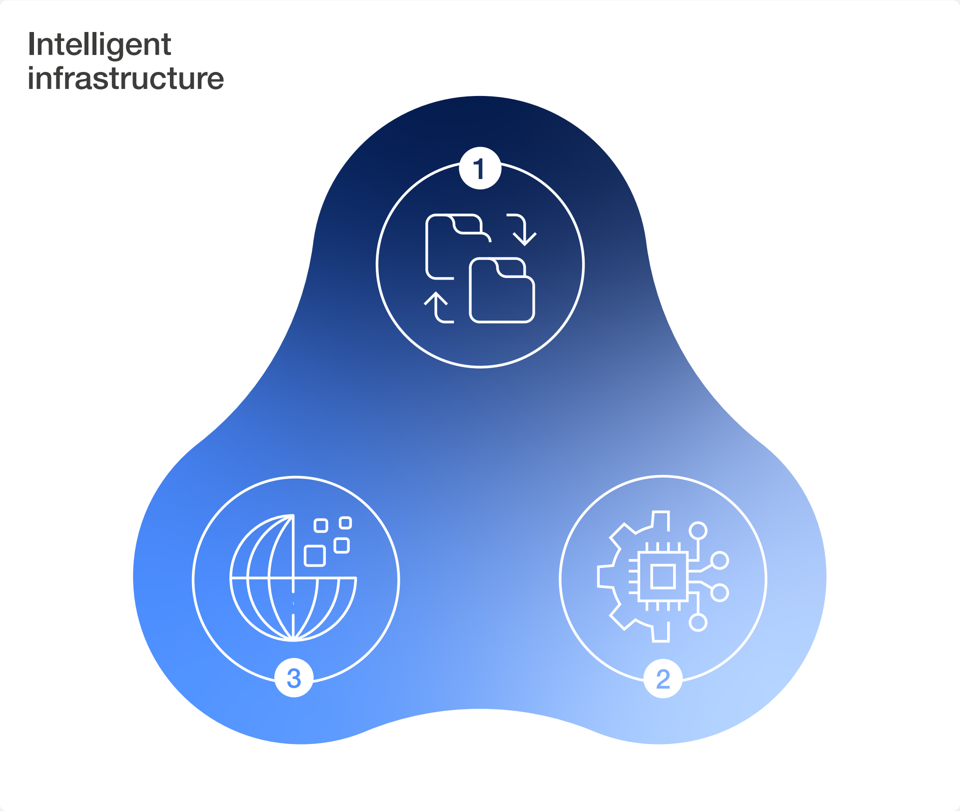
Understanding what distinguishes intelligent infrastructure from digital infrastructure is essential before examining how it is built (see Table 1).

TABLE 1 **Comparison of digital infrastructure and intelligent infrastructure**

	Digital infrastructure	Intelligent infrastructure
	Connect and automate what we already understand	Systems-intelligence by reasoning and adapting for real-time optimization
Capabilities	– Connectivity enabling data exchange – Static technology stack – Pre-programmed automation and rules-based workflows	– Shared context across platforms with cross-domain insights – Cognitive processing and continuous learning – Dynamic, self-optimizing architecture
Intelligence	– AI as isolated tools deployed on top of infrastructure (dashboards, scripts, models)	– AI embedded throughout the infrastructure stack, functioning as a governing orchestration layer that coordinates systems-level behaviour
Decision model	– Human-led, reactive	– Semi-autonomous within guardrails

Three structural features define the boundary between digital and intelligent infrastructure: interoperability, systems-intelligence and autonomy (see Figure 1).

FIGURE 1 **Three structural features that define intelligent infrastructure**



1

Interoperability

Assets exchange and interpret data seamlessly across systems, sectors and organizational boundaries

2

Systems-intelligence

AI embedded as an integrated orchestration, enabling unified cognitive processing and continuous learning

3

Autonomy

Infrastructure translates insights into real-time action, operating as an active participant in value creation

These features represent a structural shift in what infrastructure is: from a passive conduit for goods, people or data, to an active participant in value creation.

Interoperability

Intelligent infrastructure achieves deep syntactic and semantic interoperability,[6] ensuring that distinct assets, such as traffic lights, emergency vehicles and power grids, can not only exchange data via common protocols but also share a unified understanding of that data's context. Crucially, software-level interoperability through standardized APIs and middleware can enable early progress and scaling-up even while broader hardware and protocol standardization continue to evolve.

Systems-intelligence

Intelligent infrastructure embeds AI-driven intelligence across the system as an integrated orchestrated whole. This creates a unified cognitive system rather than a collection of smart but siloed components in digital infrastructure. Intelligence here means not only decision-making, but continuous learning and adaptability.

Autonomy

Intelligent infrastructure can close the loop, through translating insights into autonomous execution. Through actuators, control systems and automated workflows, intelligent infrastructure can adjust operations in real time: rerouting traffic flows, rebalancing energy loads or triggering preventive maintenance. This action-orientation transforms infrastructure from passive assets that report status to active agents that shape outcomes, operating within governance frameworks that define the boundaries of autonomous action.

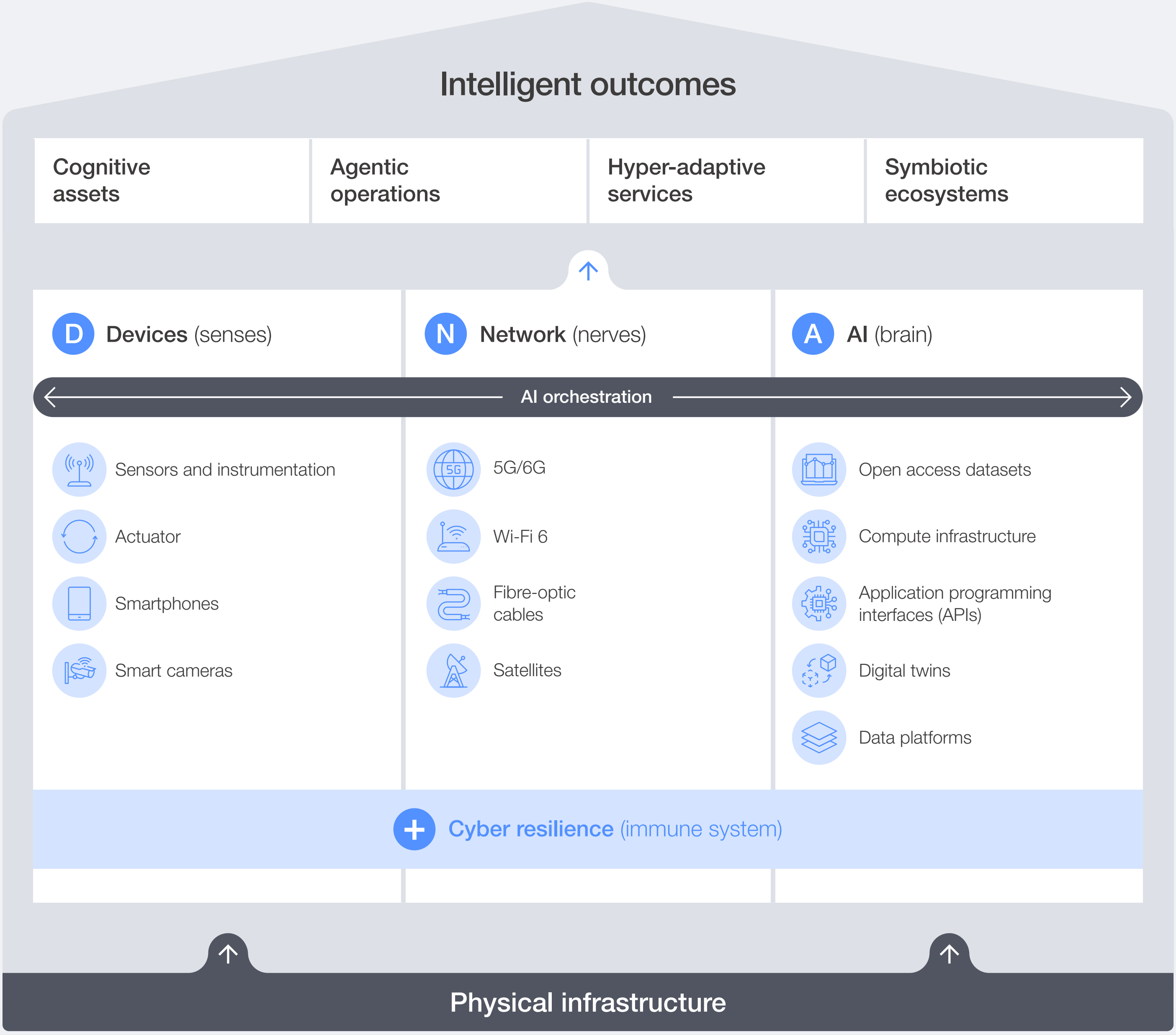
Together, these features represent not an incremental upgrade but a structural shift in what infrastructure is: from a passive conduit for goods, people or data, to an active participant in value creation. This shift also dismantles long-standing commercial barriers: data silos were preserved not for technical reasons but to protect market position. By fostering interoperability and trusted governance, intelligent infrastructure enables a move towards open and collaborative ecosystems where systematic optimization and collective gains outweigh the perceived benefits of isolated data ownership. The architecture through which this shift is realized is examined in the following chapter.

2 DNA+ framework

The DNA+ framework is a unified architecture to transform passive infrastructure into active systems that deliver intelligent outcomes.

Realizing the full potential of intelligent infrastructure requires structured investment across multiple, interdependent layers. The DNA+ framework presented in Figure 2 provides a unified architecture for designing and deploying these systems by establishing a common language that enables governments, clusters and enterprises to coordinate investments, ensure interoperability and scale up transformation systematically.

FIGURE 2 **DNA+ architecture of intelligent infrastructure**



Intelligent outcomes

Cognitive assets

Agentic operations

Hyper-adaptive services

Symbiotic ecosystems

D **Devices** (senses)

N **Network** (nerves)

A **AI** (brain)

AI orchestration

Sensors and instrumentation

Actuator

Smartphones

Smart cameras

5G/6G

Wi-Fi 6

Fibre-optic cables

Satellites

Open access datasets

Compute infrastructure

Application programming interfaces (APIs)

Digital twins

Data platforms

Cyber resilience (immune system)

Physical infrastructure

2.1 Framework overview

The abbreviation DNA+ captures the essential building blocks that enable infrastructure to sense, connect, reason and act. Much like a biological organism, each component plays a distinct, yet interdependent role. The framework comprises three core layers supported by one cross-cutting layer (see Table 2).

TABLE 2 **DNA+ framework functions**

Layer	Function	Human body analogy	Purpose	Description
D **Devices**	Intelligent sensing and control	Senses	What is happening?	Interact with physical world to collect real-time data and execute immediate, low-latency actions
N **Network**	Trusted communications	Nerves	How to transmit?	Provides reliable connectivity to transmit information between devices, platforms and actors
A **AI**	Cognitive processing and orchestration	Brain	What does it mean? What should be done?	The full AI stack: from the infrastructure that makes AI possible, through datasets and models, to AI orchestration as the governing intelligence that coordinates the entire system
+ **Cyber resilience**	End-to-end protection and recovery	Immune system	Is it secure? Can it recover quickly?	Anticipates threats, withstands attacks, recovers rapidly and adapts continuously across all layers

A defining characteristic of the DNA+ framework is that its layers are intentionally interconnected rather than independent of one another. AI capabilities from the A-layer extend across devices, network and cyber resilience. For example, edge AI embedded within sensors enables real-time perception and response at the point of data collection; AI-driven network management optimizes bandwidth allocation, predicts congestion and enables autonomous network reconfiguration; and AI-powered threat detection and adaptive response strengthen cyber resilience across the entire system.

This cross-layer nature of intelligence is not a structural ambiguity. It is precisely what distinguishes intelligent infrastructure from a collection of individually smart but disconnected components. While digital infrastructure may incorporate elements of automation and AI, intelligent infrastructure goes further: insights become actions, actions generate new data and the system learns continuously within a secure orchestrated framework at systems level.

The DNA+ layers are described in more detail below.

D Devices (senses)

The **Devices** layer forms the foundation of intelligent infrastructure – the senses that serve as the interface between the physical and digital worlds. These sensing technologies interact with the physical environment to collect real-time data and act to close the intelligence loop.

Key components

- **Sensors and instrumentation:** Environmental sensors monitoring temperature, pressure, humidity and air quality in real time; vibration monitors, flow meters and equipment health sensors that track operational performance, connected via IoT networks or existing automation systems such as SCADA.[7]
- **Identification devices:** Radio-frequency identification (RFID), near-field communication (NFC) and barcode systems for asset tracking and authentication.
- **Positioning devices:** Global positioning system (GPS), light detection and ranging (LiDAR) and indoor positioning systems for location awareness.
- **Imaging devices:** Thermal cameras, machine vision systems and multispectral sensors for visual intelligence.
- **Actuators:** Robotic systems, automated valves and smart controllers that execute responses based on analytical outputs.

COUNTRY CASE STUDY | FRANCE

Grid modernization (Linky programme)[8]

French network operator Enedis is managing the deployment of the Linky programme, an initiative to deploy smart meters across France. This programme exemplifies strategic investment in the Devices layer. The initiative deployed 37.6 million smart meters equipped with power line communication (PLC) G3 modules – a standardized protocol enabling two-way data transmission through existing electrical wiring. Each meter integrates multiple sensors capturing 10-minute interval consumption data, power quality metrics and voltage fluctuations.

The device architecture incorporates secure hardware elements for cryptographic authentication, ensuring data integrity from meter to head-end system. This sensor-dense deployment generates over 1 billion data points daily, enabling real-time demand response and remote fault detection, while reducing manual meter-reading costs by 90%.

COMPANY CASE STUDY | CHINA TOWER

“Smart Tower” strategy

China Tower transformed its passive telecoms infrastructure into an active sensing network through its “one core, two wings” strategy. By equipping 230,000 towers with high-definition cameras, weather sensors and Edge AI gateways, they turned steel towers into “digital sentinels”.[9]

These devices now serve diverse sectors, detecting forest fires for forestry departments and monitoring straw burning for agriculture bureaus. In H1 2025, revenue from this “Smart Tower” business grew 18.7%, proving that adding a sophisticated Devices layer can transform a utility cost centre into a high-growth revenue generator.[10]

Network (nerves)

The **Network** layer provides the reliable connectivity infrastructure that enables high-speed, secure data transmission throughout the intelligent infrastructure ecosystem. Serving as the nerves, this layer ensures that data captured by devices securely reaches analytical platforms and that control commands return to actuators with the speed and reliability that real-time operations demand.

Key components

- **Wired and wireless networks:** 5G and emerging 6G mobile networks, Wi-Fi 6, industrial ethernet and fibre-optic backbones.
- **Satellite/non-terrestrial networks (NTN):** Low-earth orbit (LEO) satellite constellations and integrated satellite-terrestrial architectures that extend connectivity to remote and underserved locations.
- **Communication protocols:** Message queuing telemetry transport (MQTT), open platform communications (OPC), Modbus and other industrial standards that ensure interoperability.
- **Edge gateways and routers:** Intelligent networking equipment that manages data flows and enables distributed computing at the network edge.

COUNTRY CASE STUDY | CHINA

5G + Industrial Internet initiative

A national Network layer strategy combining connectivity rollout, spectrum policy and industrial incentives can accelerate private sector adoption at a pace and scale that individual enterprise investment cannot achieve alone. China deploys perhaps the world's largest intelligent infrastructure network with 4.2 million 5G base stations forming the connectivity backbone for industrial operations across vast geographic distances.

Through the Industrial Internet Development Action Plan (2021-2023), this national deployment catalysed the establishment of more than 4,000 5G-powered factories and standardized industrial 5G modules at scale, driving down deployment costs.[11] This policy model combined top-down spectrum allocation and infrastructure mandates with sector-specific incentives for private 5G adoption. In 2024, 15 provinces reported industrial internet sector growth rates of 7%, outpacing national GDP growth,[12] reflecting the compounding returns of network-layer investment on broader industrial output.

COMPANY CASE STUDY | ARAMCO

Industrial private 5G deployment

Aramco has spearheaded the modernization of its Network layer by deploying one of the world's largest industrial private 5G networks, specifically designed to support its expansive oil and gas facilities. By utilizing a 5G 450 MHz industrial spectrum, the architecture provides a high-reliability, low-latency backbone that connects thousands of intelligent edge devices, including autonomous robots, drones and IIoT sensors across remote production sites.[13]

To manage this infrastructure, Aramco utilizes software-defined networking (SDN) to achieve intelligent orchestration, which is critical for its "mesh" network trials that extend high-speed connectivity to offshore sites.[14] This robust connectivity serves as the foundation for its "Digital Lighthouse" facilities, where the seamless flow of data between Devices and AI layers has contributed to significant gains in productivity and a reduction in energy intensity through optimized remote operations.

AI (brain)

The **AI** layer is the cognitive centre of intelligent infrastructure. It is a full-stack concept, encompassing everything from the foundational compute infrastructure that makes AI possible through to the governing intelligence that coordinates the entire system.

Key components

Three tiers of capability build upon one another within this layer:

- **AI infrastructure**: Provides the computational foundation, including data centres, compute capacity, cloud and edge computing platforms, and data integration pipelines and lakes.

At the national level, strategic investment in compute capacity constitutes foundational infrastructure policy.

- **AI assets**: Transform data into intelligence, including datasets, AI models, analytics platforms and digital twins that enable pattern recognition, prediction and prescriptive decision-making. This tier encompasses the shift from predictive analytics (what is likely to happen) through prescriptive analytics (what should be done) to agentic analytics (do it). At the national level, investment in sovereign, open-access datasets and domain-specific models is increasingly central to industrial competitiveness.
- **AI orchestration**: Acts as the highest-order function of this layer and the capability that most clearly distinguishes intelligent infrastructure from digital infrastructure with AI applications added. Whilst the first two tiers provide intelligence within specific domains, AI orchestration provides governing intelligence that coordinates AI systems across the entire DNA+ architecture. This ensures that they operate as a unified cognitive system rather than a collection of isolated, smart components. At the national level, establishing the governance frameworks and technical standards to deploy and oversee AI orchestration at scale is a defining infrastructure challenge.

> **“ At the national level, establishing the governance frameworks and technical standards to deploy and oversee AI orchestration at scale is a defining infrastructure challenge.**

COUNTRY CASE STUDY | 🇰🇷 SOUTH KOREA

National AI Strategy

South Korea’s National AI Strategy exemplifies how a government can integrate the AI layer systematically across all three capability tiers (AI infrastructure, AI assets, AI orchestration) simultaneously, with the explicit ambition of becoming a top-three global AI power. The strategy targets expanding national compute capacity to over two exaflops,[15] establishing a KRW 2 trillion National AI Computing Centre complemented by KRW 65 trillion (approximately $47 billion) in mobilized private investment through 2027, providing shared infrastructure accessible to research institutions, startups and industry, and accelerating nationwide AI transformation to achieve a 70% AI adoption rate in industry and 95% in the public sector by 2030.[16]

The Ministry of Science and ICT (MSIT) is advancing a Sovereign AI Foundation Models project – incorporating NVIDIA NeMo and open datasets – to develop sovereign language models that enterprises, researchers and startups can use to build AI agents and applications.[17] A presidential-level National AI Strategy Committee has been established as Korea’s national AI command centre, providing unified governance across ministries and coordinating the full national AI deployment agenda.[18]

COMPANY CASE STUDY | CONTEMPORARY AMPEREX TECHNOLOGY LIMITED (CATL)

Intelligent battery manufacturing

As the world’s largest battery manufacturer, CATL has deployed AI as an orchestration layer across its manufacturing operations, integrating equipment, process and quality data into a unified, continuous learning platform. CATL’s intelligent manufacturing architecture combines seven enabling technologies, including AI, digital twins, 5G and edge computing, into a single industrial platform. Five data platforms consolidating over 100 billion data assets provide the foundation for systems-level AI reasoning across R&D, manufacturing and after-sales operations with a 5G enterprise network covering over 95% of production equipment and more than 7,000 quality control points monitored in real time.[19]

The AI orchestration layer coordinates across these systems simultaneously. Digital twins have increased manufacturing productivity by 25%, while AI-powered quality detection has driven battery cell failure rates from parts-per-million to parts-per-billion levels.[20] CATL’s Intelligent Cell Design platform, recognised with the World Economic Forum’s MINDS Award, combines physics-based models with agentic AI, drawing on over 50 million data records to automate battery design generation and refinement.[21]

Cyber resilience (immune system)

Like an immune system that strengthens and protects the entire human body, cyber resilience provides the ability to minimize the end-to-end impact of significant cyber incidents across all DNA components, ensuring that infrastructure can continue to operate, survive and adapt when cyber incidents occur.[22]

This represents a fundamental evolution beyond traditional cybersecurity. While cybersecurity focuses primarily on protecting systems, networks and data from attacks and adverse cyber events, cyber resilience assumes that breaches are inevitable in today's complex and sophisticated threat landscape. It therefore encompasses an organization's ability to anticipate, protect against, withstand, recover from and adapt to adverse cyber events.

This evolution from focusing solely on prevention to ensuring continuity and adaptability in the face of disruption is critical for intelligent infrastructure. As digital and physical systems become increasingly interconnected, attack surfaces grow more complex and dynamic, making absolute protection unrealistic. Cyber resilience therefore ensures that essential functions remain operational; recovery is swift and coordinated and systems are strengthened over time through continuous learning and adaptation.

Key considerations

- **Ensure organizational alignment**, prioritizing security and resilience alongside performance and operational efficiency across people, processes and assets.
- **Establish clear governance and accountability structures**, particularly where infrastructure components are owned or operated by multiple entities.
- **Implement robust supply chain and vendor risk management**, with defined cybersecurity requirements enforced contractually across vendors, OEMs and integrators, including visibility into third-party updates, remote access and maintenance practices.
- **Enhance cyber defence operations with technological advances in AI**,[23] including threat detection analyses, behavioural pattern analysis, vulnerability management and prioritization, predictive threat intelligence, and autonomous response and remediation at machine speed.

COUNTRY CASE STUDY | SINGAPORE

Smart Nation initiative: integrating AI infrastructure with national cyber resilience[24]

Under the Smart Nation 2.0 initiative,[25] Singapore has deployed nationwide digital infrastructure integrating IoT sensors with AI analytics and secure government platforms to optimize mobility, utilities and public services, such as traffic and water supply. These AI-enabled infrastructure systems have reduced traffic congestion by up to 15% on key corridors, while smart water management has lowered water losses by around 5% in monitored areas.

To safeguard its digital infrastructure and ensure cyber resilience, Singapore has established a national cybersecurity architecture led by the Cyber Security Agency of Singapore (CSA). Critical services fall under the Critical Information Infrastructure (CII) framework, which mandates cybersecurity controls and resilience exercises across 11 essential sectors. This is supported by the Operational Technology (OT) Cybersecurity Masterplan, co-created with more than 60 organizations in 2024, which embeds resilience-by-design principles into industrial systems, with 14 organizations committing to secure-by-deployment practices. National cyber exercises involving 500+ participants further strengthen recovery readiness and cross-sector coordination. Together, these measures show how Singapore combines AI-enabled optimization with enforceable cyber resilience at national scale.

COMPANY CASE STUDY | DUKE ENERGY AND DRAGOS

Active defence through AI-driven threat-hunting platform

US utilities company Duke Energy has moved beyond passive firewalls to active defence. By deploying AI-driven threat hunting platforms (e.g. Dragos), the company monitors industrial networks for behavioural anomalies, such as commands that are technically valid but contextually malicious (e.g. opening a breaker without a fault condition).[26] This approach provides deep visibility into the "proprietary protocols" of industrial control systems, allowing operators to detect and isolate compromised assets before they can disrupt the grid. It represents a shift from preventing access to ensuring resilience in a converged IT/OT environment.[27]

2.2 Intelligent outcomes

> The fundamental value proposition of intelligent infrastructure: transforming passive systems into active participants in value creation that can perceive, analyse, decide and act with increasing autonomy.

Intelligent outcomes represent the transformative innovations that emerge when organizations successfully invest in and deploy intelligent infrastructure. This is the value creation layer, delivering tangible benefits across four dimensions:

- Cognitive assets
- Agentic operations
- Hyper-adaptive services
- Symbiotic ecosystems

These intelligent outcomes enable organizations to move beyond basic monitoring and automation towards reasoning and agency. This progression represents the fundamental value proposition of intelligent infrastructure: transforming passive systems into active participants in value creation that can perceive, analyse, decide and act with increasing autonomy.

Cognitive assets

Cognitive assets refer to physical systems embedded with intelligence that enables them to understand their environment, anticipate requirements and optimize their own performance. These assets transform themselves from passive equipment into active participants in value creation, capable of self-monitoring, self-diagnosis and self-optimization. They can anticipate failures before they occur, schedule maintenance during optimal windows and continuously improve their operational parameters based on historical performance data.

COUNTRY CASE STUDY | UNITED KINGDOM

UK Power Networks' smart grid

UK Power Networks is widely recognised as a global leader in smart grid development, ranking first worldwide in the Smart Grid Index, which assesses utilities' capabilities in monitoring, automation and data analytics.[28] Through its smart grid innovation programmes, the company has deployed thousands of grid monitoring devices, including line sensors and intelligent substations, to improve real-time fault detection, network visibility and operational decision-making.

UK Power Networks also integrates large-scale smart meter data and advanced analytics to support faster fault identification, validation of restorations and more efficient network operation, illustrating how electricity networks are evolving towards more self-monitoring and adaptive infrastructure systems.[29]

Agentic operations

Agentic operations represent the ability of intelligent infrastructure to act autonomously with defined guardrails, moving beyond rigid automation to systems that can perceive, decide and act independently. While cognitive assets focus on intelligence embedded at the object or asset level, agentic operations operate at the process level, enabling end-to-end workflows to self-direct and continuously optimize. This capability enables organizations to achieve operational excellence through continuous optimization with minimal human intervention. It is enabled by the progression from predictive and prescriptive analytics to agentic analytics within the AI layer, showing the shift from knowing what should be done to autonomously doing it.

In a manufacturing context, agentic operations manifest in various ways, for example through autonomous quality control systems that detect anomalies, trace root causes, adjust parameters and schedule predictive maintenance. These systems become more capable over time through machine learning, creating a virtuous cycle of improvement that human operators alone could not achieve.

COMPANY CASE STUDY | FOXCONN

Self-controlling factory

Foxconn's facility in Shenzhen, China, operates as a fully autonomous production environment where industrial robots and AI systems manage manufacturing processes with minimal human presence. This implementation of agentic operations has achieved a 30% increase in production efficiency, demonstrating the transformative potential of autonomous industrial systems.[30]

Hyper-adaptive services

Intelligent infrastructure enables hyper-adaptive services to deliver personalized, context-aware services that respond dynamically to changing conditions and individual requirements. These services move beyond static offerings to provide real-time adaptation based on comprehensive data analysis and predictive capabilities.

In urban contexts, hyper-adaptive services enable intelligent traffic management that adjusts signal timing based on real-time flow patterns, emergency vehicle movements and predicted congestion. In industrial settings, these services might include dynamic supply chain routing that responds automatically to disruptions, weather events or demand fluctuations.

COMPANY CASE STUDY | PORT OF HAMBURG

smartPORT Logistics

The Port of Hamburg's smartPORT logistics initiative uses digital intelligence and sensor networks to improve flows of traffic and goods through the port's infrastructure. This system integrates real-time data from trucks, vessels and yard operations to make logistics more efficient and transparent, such as through digital truck slot booking and traffic flow optimization.[31]

By enhancing visibility of available capacity and coordinating movements, the smartPORT logistics initiative supports more dynamic use of yard and terminal resources in response to changing demand across the port ecosystem.[32]

Symbiotic ecosystems

Symbiotic ecosystems represent the highest level of intelligent infrastructure maturity, where multiple organizations, systems and stakeholders operate in coordinated, mutually beneficial relationships enabled by shared intelligent infrastructure. These ecosystems create network effects where the value generated exceeds what any single participant could achieve independently.

The development of symbiotic ecosystems requires not only technical integration but also governance frameworks, data-sharing agreements and trust mechanisms that enable collaboration while protecting proprietary interests. Industrial clusters and smart cities represent primary contexts for symbiotic ecosystem development.

CLUSTER CASE STUDY | NET-ZERO ORDOS-ENVISION INDUSTRIAL PARK

Intelligent AIoT management system

The Net-Zero Ordos-Envision Industrial Park[33] in Inner Mongolia, China demonstrates true industrial symbiosis enabled by intelligent infrastructure. The park deploys a shared “Intelligent AIoT” management system that integrates real-time data from over 56 co-located companies, battery storage stations and renewable energy assets. Acting as the cluster’s “brain”, this platform autonomously balances energy supply and demand across the entire ecosystem, allowing companies to share excess renewable power and storage capacity. This symbiotic coordination has reduced electricity costs by approximately 10% and can enable the park to operate on 100% green energy – an outcome no single tenant could have achieved in isolation.

3 Company, Cluster, City, Country – 4C outcomes

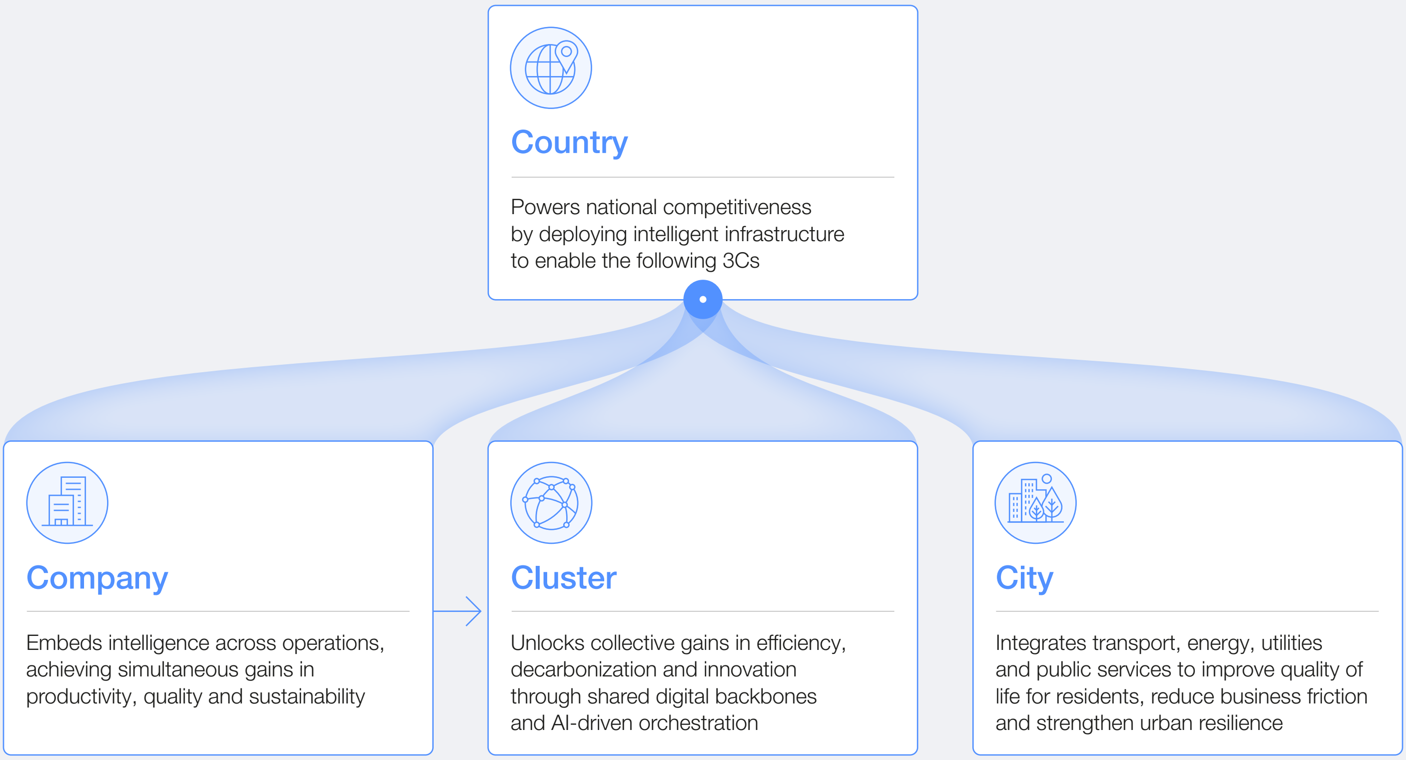
Those that embrace intelligent infrastructure will unlock innovations and efficiencies that others limited to passive digital infrastructure cannot achieve.

As we move deeper into the intelligent age, the gap between entities that rely solely on digital connectivity and those that adopt intelligent infrastructure will become increasingly significant. Organizations and nations that make the leap to truly intelligent infrastructure will unlock innovations and efficiencies that are structurally impossible for those limited to passive digital infrastructure. This transition is not merely a matter of incremental advantage; it is a prerequisite for economic relevance in an increasingly agentic and intelligent global economy.

Intelligent infrastructure delivers value that transcends individual assets, creating a network effect where the economic output exceeds the sum of its parts. To understand the full scope of this impact, this chapter analyses the transformation across four distinct but interconnected levels: Company (micro), Cluster (meso-industrial), City (meso-urban) and Country (macro). These "4C outcomes" demonstrate how intelligent infrastructure enables countries to compete, cities to thrive, clusters to innovate and companies to lead.

The relationship between these levels is multiplying rather than additive. Companies that embed intelligence across their operations achieve individual gains in productivity, quality and sustainability. When those same companies collaborate within a cluster – sharing data, infrastructure and AI-driven coordination – they unlock further collective value that no single firm could generate independently. Cities, clusters and companies each contribute distinctly to national competitiveness, while national frameworks in turn set the standards, governance conditions and foundational investment that make all three possible. It is this two-way, reinforcing dynamic – not a linear chain of command – that gives intelligent infrastructure its systemic impact.

FIGURE 3 **4C beneficiaries**



Country

Powers national competitiveness by deploying intelligent infrastructure to enable the following 3Cs

Company

Embeds intelligence across operations, achieving simultaneous gains in productivity, quality and sustainability

Cluster

Unlocks collective gains in efficiency, decarbonization and innovation through shared digital backbones and AI-driven orchestration

City

Integrates transport, energy, utilities and public services to improve quality of life for residents, reduce business friction and strengthen urban resilience

3.1 Company outcomes: operational excellence

> Agentic operations deliver what may be termed “hyper-productivity”: simultaneous gains in speed, quality and sustainability that were previously considered trade-offs.

At the micro-level, intelligent infrastructure enables a fundamental transformation from automated operations to agentic operations – systems that can sense, decide and act with increasing autonomy within defined guardrails. This shift delivers what may be termed “hyper-productivity”: simultaneous gains in speed, quality and sustainability that were previously considered trade-offs.

Traditional automation follows predetermined scripts: machines execute precisely what they are programmed to do. Intelligent infrastructure enables a qualitative shift to agentic operations, where systems possess the real-time context and cognitive capabilities to optimize operations without constant human intervention.

This transformation manifests across multiple dimensions of enterprise performance:

- **Enhanced productivity:** Real-time optimization and predictive maintenance can reduce unplanned downtime, while autonomous quality control enables continuous process improvement.
- **Accelerated market response:** Agile manufacturing and dynamic supply chains allow companies to pivot production lines rapidly in response to demand signals, reducing time-to-market for new products.
- **Quality transformation:** AI-driven inspection enables quality standards (such as parts-per-billion defect rates) that were previously impossible to achieve at production speed.
- **Resource optimization:** Intelligent systems achieve higher outputs with lower energy and material inputs, decoupling growth from resource consumption.

COMPANY CASE STUDY | SIEMENS NUMERICAL CONTROL (NANJING)

Digital twin and AI-enabled systems-level intelligence

Siemens Numerical Control (SNC)[34] in Nanjing, China, operates in a high-mix, low-volume manufacturing environment requiring line reconfigurations every four weeks, with delivery windows compressed from 45 days to 10. To meet these demands, SNC Nanjing deployed end-to-end digital twins, modular automation and more than 50 AI-driven use cases, embedding intelligence across the full production architecture rather than in isolated applications. The outcomes span all three performance dimensions simultaneously:

- Operational efficiency improved markedly, with lead times falling 78% and time-to-market by 33%.
- Quality performance followed, with field failure rates declining 46%.
- Sustainability gains were achieved in parallel: scopes 1 and 2 carbon emissions fell by 28% which is a direct result of AI-optimized resource management rather than a separate initiative.

Recognised by the World Economic Forum’s Global Lighthouse Network in January 2026, SNC Nanjing demonstrates that systems-level intelligence enables productivity, quality and sustainability to reinforce rather than compete with one another.

3.2 Cluster outcomes: collaborative innovation

Intelligent infrastructure has the potential to transform co-located companies within industrial clusters from isolated actors into interconnected, intelligent ecosystems – enabling synergies, resilience, innovation and shared value creation at scale.

Industrial clusters concentrate assets, energy systems, logistics flows and supply chains within defined geographies. Yet without coordinated collaboration, these assets operate largely in parallel. Intelligent infrastructure changes this dynamic: by combining shared digital backbones, interoperable data platforms and systems-level orchestration, clusters can leverage scale, complementary supply and demand profiles and shared optimization opportunities to achieve outcomes no single organization could realize independently.

Digital maturity at cluster level is not simply about deploying technology – it requires governance, trust, shared standards and aligned incentives.

The World Economic Forum's briefing paper *Five Steps for Digital Collaboration in Industrial Clusters* highlights that digital maturity at cluster level is not simply about deploying technology – it requires governance, trust, shared standards and aligned incentives. When these foundations are in place, intelligent infrastructure becomes the enabling layer for cluster-wide transformation.

Cluster-level transformation typically unfolds across five interrelated pathways, outlined below.

Shared infrastructure development

Capital-intensive assets, including carbon capture and storage (CCS) networks, hydrogen systems and shared utilities, can become financially viable when demand and investment are pooled across co-located firms. By enabling aggregated demand forecasting and coordinated capacity planning, intelligent infrastructure reduces utilization risk and revenue volatility, strengthening the investment case for shared assets and enabling structured public-private financing models. Similarly, clusters can deploy shared digital infrastructure such as IoT platforms and private 5G networks to serve multiple co-located companies, dramatically lowering barriers to digital participation and accelerating the diffusion of innovation.

Operations and process optimization

Real-time monitoring, predictive maintenance and trusted cross-company data collaboration enable shared utilities, logistics flows and selected production schedules to be dynamically coordinated. Rather than focusing solely on firm-level efficiency, intelligent infrastructure creates shared operational visibility across interconnected assets. This allows clusters to synchronize production cycles, anticipate disruptions, adjust to demand fluctuations and respond collectively to operational risks. The result is improved reliability, reduced downtime, faster decision-making and greater system resilience – enabling the cluster to function as an integrated operating environment rather than a set of isolated facilities.

Resource efficiency and circularity

Shared data platforms, enhanced by AI-driven analytics, enable industrial symbiosis at scale, such as redirecting waste heat, reusing by-products as feedstock or allocating renewable energy generation across multiple demand profiles in real time. What would otherwise remain theoretical efficiency gains become operationally realizable when data flows continuously and in real time across cluster participants. Intelligent infrastructure provides the coordination and decision-support layer that transforms theoretical efficiencies into operational realities – delivering lower emissions, reduced waste and enhanced competitiveness.

Commercial optimization and trading

Industrial clusters can strengthen commercial performance by engaging external markets in a coordinated manner. By aggregating demand, generation capacity and flexibility across firms, clusters gain greater bargaining power in procurement, improve forecasting accuracy and participate more effectively in energy and commodity markets. This shared market visibility enables more competitive contracting, better risk management and faster response to price volatility than firms acting independently.

Environmental and risk management

Cluster-level visibility strengthens environmental compliance and risk oversight across interconnected assets and operations. By enabling information exchange across the ecosystem, intelligent infrastructure makes shared exposures – such as emissions, safety incidents and operational disruptions – transparent at system scale. This allows coordinated emissions tracking, earlier detection of anomalies and streamlined regulatory reporting based on standardized metrics. Compared with fragmented firm-level monitoring, a shared data architecture improves situational awareness, reduces cascade risks and supports more proactive and credible compliance management.

CLUSTER CASE STUDY | BASQUE COUNTRY (SPAIN)

Net-Zero Basque Industrial Super Cluster

This initiative, funded by Horizon Europe, represents a leading example of “collective intelligence” in industrial decarbonization, connecting heavy industries – including refining, pulp and paper, lime and steel production and a public wastewater treatment plant – located in the highly industrialized area of the Basque Country. The cluster deployed a shared data framework to identify cross-industry synergies within the Basque Industrial Hub for Circularity (BIH4C).[35] Instead of isolated efficiency improvements, the cluster utilizes a shared platform to map material and energy flows. For instance, it identifies synergies such as utilizing oxygen by-products from refinery electrolysis to fuel oxy-combustion processes in the neighbouring steel industry or capturing CO_2 from lime production to produce synthetic fuels.[36]

Through these circular synergies, participating companies in the BIH4C project aim to reduce CO_2 emissions by 20% and resource consumption by 10% in the coming years.[37] This transformation is critical for safeguarding the competitiveness of the industrial sector, which serves as the region’s economic engine, contributing approximately 24% of the Basque Country’s GDP.[38]

3.3 City outcomes: urban competitiveness and resilience

At the city scale, intelligent infrastructure transforms metropolitan regions from fragmented service networks into integrated economic platforms. While cities have long deployed sensors and analytics across transport, energy, water and public safety, these systems often operate independently. Intelligent infrastructure connects them through interoperable and trusted data exchange, enabling coordinated, real-time action, predictive risk management and more efficient service delivery. Key to scaling-up intelligent infrastructure in cities is establishing governance frameworks that build civic trust, enable secure data sharing and set clear mandates for cross-agency coordination.

Intelligent infrastructure strengthens urban competitiveness across four structural dimensions, outlined below.

> Intelligent infrastructure connects systems through interoperable and trusted data exchange, enabling coordinated, real-time action, predictive risk management and more efficient service delivery.

Productivity and economic performance

Congestion, permitting delays, infrastructure failures and service fragmentation impose measurable costs on businesses. Integrated urban systems reduce these frictions through coordinated mobility management, improved grid visibility and streamlined regulatory processes. When infrastructure operates predictably and efficiently, firms face lower transaction costs and benefit from higher effective productivity.

Financial performance and investability

Cities face mounting fiscal pressure from ageing assets, climate adaptation and rising service expectations. Shared data and asset intelligence improve maintenance planning, extend infrastructure lifecycles and reduce operating costs. Greater transparency and performance tracking also support more predictable, investment-ready project pipelines that attract private capital.

Resilience and risk mitigation

Urban systems are increasingly exposed to climate shocks, cyber threats and infrastructure interdependencies. Cross-domain coordination enables cities to anticipate cascading failures and respond before disruptions escalate. Real-time modelling and integrated response capabilities strengthen flexibility, allowing infrastructure to absorb shocks, recover faster and adapt over time.

Quality of life and good growth

Urban competitiveness depends on liveability and attracting talent. More reliable transport, streamlined services, reduced delays and better resource management translate into shorter commutes, fewer disruptions and greater predictability for residents and businesses. By reducing everyday friction, intelligent infrastructure supports economic dynamism while improving environmental performance and quality of life.

CITY CASE STUDY | SEOUL

Integrated urban resilience platform

Seoul has advanced from deploying individual smart city solutions to building an integrated Smart City Data Hub that connects transport, safety, environmental monitoring and public utilities into a shared intelligence platform that supports real-time data sharing and predictive analysis.[39] The platform integrates traffic systems, CCTV networks, flood sensors and public transport data, applying AI models to forecast congestion, optimize emergency routing and anticipate climate-related risks.[40]

By embedding interoperable data exchange and coordinated response into its infrastructure, Seoul has improved the city's ability to manage systemic risk and strengthened its operational reliability in one of the world's most densely populated metropolitan regions. This illustrates how intelligent infrastructure at the city scale moves beyond sensors and dashboards towards integrated, predictive urban management.[41]

As economic activity concentrates in metropolitan regions, city performance increasingly shapes national productivity.

3.4 Country outcomes: strategic competitiveness

At the national level, intelligent infrastructure has become a primary determinant of competitiveness. Countries are no longer competing solely on labour costs or natural resource endowments, but increasingly on their capacity to provide the intelligent backbone that modern economies require, one that attracts high-value investment, enables industrial transformation and builds economic resilience over time. The decisions governments make today about infrastructure architecture, governance and investment will compound across decades.

Country-level intelligent infrastructure creates value across four reinforcing pathways, outlined below.

> Countries are no longer competing solely on labour costs or natural resource endowments, but on their capacity to provide the intelligent backbone that modern economies require.

Investment attraction and industrial positioning

As global firms increasingly make location decisions based on digital and AI readiness, countries with reliable intelligent infrastructure signal a credible operating environment for advanced industries.[42] Connectivity, compute access, data governance frameworks and interoperability standards function together as a national competitiveness signal that shapes where manufacturing capacity, R&D functions and headquarters locate.

Standards and policy leadership

Governments occupy a unique position in the intelligent infrastructure ecosystem. By establishing interoperability standards, data governance frameworks and regulatory environments that enable experimentation, they lower the cost of adoption across the entire economy and prevent the fragmentation that would otherwise constrain network effects. Countries that move early on standards-setting create durable advantages, as firms and investors align their architecture to national frameworks rather than waiting for clarity.

Productivity and industrial upgrading

National intelligent infrastructure lowers the cost and complexity of AI adoption at the firm level, enabling productivity gains to diffuse across industries rather than concentrate in leading companies. Shared compute platforms, open data standards and interoperable industrial networks create systemic conditions for economy-wide efficiency improvement. Further, intelligent optimization of critical resources such as energy and water unlocks system capacity, reducing input costs across the economy and supporting sustained GDP growth.

Economic resilience and sovereignty

As infrastructure systems become increasingly data-driven and interconnected, national control over the intelligence layer, including data governance, AI model development and cybersecurity architecture, becomes a dimension of economic sovereignty. Countries that build domestic capability in these areas are better positioned to absorb external shocks and maintain strategic autonomy in a more fragmented global economy.

COUNTRY CASE STUDY | UNITED ARAB EMIRATES (UAE)

Intelligent infrastructure as a national economic strategy

For the United Arab Emirates (UAE), intelligent infrastructure is not a technology agenda but a national economic strategy. Facing the long-term imperative to diversify beyond hydrocarbons, the country has pursued a systematic build-out of AI-ready infrastructure, spanning sovereign compute capacity, data centre ecosystems and AI governance frameworks, as the foundation for a post-oil economy.

Non-hydrocarbon activities now contribute more than 70% of GDP and UAE recorded 4% real GDP growth in 2024 driven primarily by non-oil sectors.[43] In 2024, it was ranked the world's leading FDI destination relative to the size of its economy, with Abu Dhabi and Dubai ranked first and second globally for data centre attractiveness.[44]

This positioning reflects deliberate investment at scale: since the beginning of 2024, UAE has committed $148 billion in AI-related investment domestically and internationally.[45] At the operational level, the Abu Dhabi National Oil Company (ADNOC)'s ENERGYai platform, trained on 80 years of proprietary data, demonstrated a 70% improvement in seismic interpretation accuracy in early 2025 trials.[46] Together, these outcomes illustrate how national intelligent infrastructure investment can structurally reposition an economy, attracting capital and technology partnerships that compound competitiveness over time.

3.5 Broader societal outcomes

“ Intelligent infrastructure creates the conditions for more inclusive economies, more responsive public services and more sustainable patterns of growth.

Beyond economic metrics, intelligent infrastructure drives structural improvements in society and governance. These benefits extend beyond productivity and competitiveness to reshape how societies function and how governments serve their citizens. Intelligent infrastructure creates the conditions for more inclusive economies, more responsive public services and more sustainable patterns of growth.

Fostering inclusive growth

By lowering the cost of digital access and standardizing interfaces, intelligent infrastructure democratizes access to advanced technology. It allows SMEs to plug into global value chains without the prohibitive capital costs of building their own proprietary networks. For example, China’s industrial internet platforms enable SMEs to access cloud-based design, manufacturing and logistics services that were previously affordable only to large firms, significantly reducing barriers to digital participation.

Data-driven governance

Intelligent infrastructure transforms public services from reactive to proactive entities. Governments equipped with real-time data on energy usage, traffic and air quality can make evidence-based policy decisions, improving the quality of public services and urban living. In cities such as Singapore, integrated transport and urban sensing systems enable authorities to dynamically manage traffic flows and public transport capacity based on real-time demand, improving service reliability and urban liveability.

Sustainability and resource optimization

Perhaps most critically, intelligent infrastructure decouples economic growth from resource consumption and allows societies to do more with less. Through precise monitoring, industries can achieve higher outputs with lower energy and material inputs. This transition from mass production to high-efficiency, high-tech production is essential for meeting global climate goals while sustaining development. Smart energy grids and virtual power plants – such as those deployed in South Australia[47] – allow higher renewable penetration while maintaining grid stability, supporting economic growth with lower carbon intensity.

Enhancement of living standards

Analysis of country-level data shows a strong positive correlation between infrastructure maturity and composite human development outcomes, encompassing health, education and income mobility. Countries with more developed infrastructure consistently achieve higher scores on the Human Development Index, suggesting that infrastructure functions as a foundational lever for broader societal progress.[48] Intelligent infrastructure amplifies this relationship further by enabling more efficient public services, lowering barriers to digital participation and supporting sustainable resource use; in doing so, it translates systemic efficiency gains into tangible improvements in daily life across income levels.

Realizing these broader societal outcomes, however, is not straightforward. The benefits of intelligent infrastructure are not self-distributing but depend on deliberate decisions about how systems are governed, how investment is structured and how capabilities are built. The next chapter examines the four deployment imperatives that determine whether the potential of intelligent infrastructure translates into sustained and equitable impact across the 4Cs.

4

Deployment imperatives

Alignment on institutional challenges is critical to realize the full potential of intelligent infrastructure.

Insights from the many one-to-one consultations with multi-stakeholder experts and six in-person workshops globally in 2025 led by the Forum converges on one consistent finding: most of the technology for intelligent infrastructure already exists. The primary barriers are not technical, they are institutional – in particular, the challenge of aligning governance, incentives, financing and trust across actors who have historically operated in silos.

This chapter identifies four deployment imperatives that are foundational in ensuring intelligent infrastructure delivers its full potential: governance, trust, investment and capability.

4.1 Governing the transition

> Most of the technology for intelligent infrastructure already exists. The primary barriers are not technical, they are institutional.

Public institutions, together with international standard-setting bodies and industry-led consortiums, play a foundational (although not prescriptive) role in enabling intelligent infrastructure. Where regulatory frameworks remain fragmented or unclear, investment stalls even when demand is strong: companies cannot commit capital when rules governing data ownership or liability are unresolved.

Where shared standards and governance frameworks have been established – such as in Singapore through its Digital Economy Framework for Action[49] or in the European Union through GAIA-X,[50] which aims to develop a secure, federated and open data infrastructure ecosystem – private investment has followed at scale.

Three governance imperatives stand out as universally applicable, regardless of a country's income level or institutional context, outlined below.

Interoperability standards

Intelligent infrastructure only delivers its full value when systems can communicate across organizational and sectoral boundaries. Without semantic standards for data interpretation and protocol standards for communication, the network effects cannot materialize. Establishing these standards or actively participating in international standard-setting bodies – such as the International Telecommunications Union (ITU) and the International Standards Organization (ISO) – are critical high-leverage actions for any government to take.

Both China and the United States have demonstrated that progress requires dedicated multi-stakeholder anchors. China's Alliance of Industrial Internet[51] is a government-guided platform that convenes industry, academia and research

institutes to embed interoperability into national standards; while in the United States, the Industry IoT Consortium, now integrated into the Digital Twin Consortium,[52] is a comparable, but more industry-led partnership that spans technology companies, government agencies and academia.

Data governance frameworks

As physical assets become data-generating systems, questions of data ownership, access rights, quality assurance and sovereignty become fundamental infrastructure questions. Effective data governance is not primarily a technical challenge; it is a political and institutional one. Frameworks should be clear enough to support commercial decisions, flexible enough to accommodate innovation and trusted enough that actors are willing to share the data that creates collective value.

The European Union's Data Act[53] and South Korea's Data Industry Promotion Plan[54] offer instructive models of how governments can create the foundations for data-driven industrial ecosystems without mandating specific technologies.

Regulatory environments that enable experimentation

Intelligent infrastructure often requires deploying technologies, such as AI-driven autonomous systems, cross-sectoral data platforms and IT/OT-integrated networks, in contexts where existing regulatory frameworks were not designed for them. Regulatory sandboxes, as deployed in Singapore for smart urban systems and in several EU member states for industrial AI applications, allow controlled deployment that generates evidence for both operators and regulators, enabling regulatory frameworks to evolve alongside technology rather than constraining it.

4.2 Trust as infrastructure

Across the case studies presented earlier – from port logistics to industrial clusters to smart city platforms – the decisive factor in whether data-sharing and collaborative intelligence could be achieved is not technology but trust: the confidence of each participant that sensitive information shared with a neutral platform would be used fairly, governed transparently and protected from misuse by competitors.

Deployment experience across 4Cs points to three consistent design principles, outlined below.

Value demonstrated at the individual level

Aggregate efficiency gains are not sufficient motivation if individual participants cannot see their own return. The benefits of participation must be demonstrable at the level of each actor, with clear attribution of value back to the data and capabilities each participant contributes.

Credible, neutral orchestration with built-in protections

Cluster-level intelligent infrastructure requires an orchestrator perceived as sufficiently neutral – an entity that can credibly administer shared platforms without being seen as advantaging any one actor. In practice, this role may be played by a port authority, an industry association or a public body; what matters is that governance is structured to prevent any single participant from shaping the platform's terms in its own interest.

This is particularly critical where large enterprises serve as anchor participants: while they typically provide the data volume and capital that get shared platforms off the ground, governance protections for smaller actors must be built in from the outset, not retrofitted after the platform has achieved scale.

Phased participation to lower barriers to entry

Not all actors need to share at the same depth or at the same time. Systems that allow participants to begin with low-sensitivity data, such as asset availability, aggregate energy demand or logistics timing windows, reduce the perceived risk of entry and are particularly important for SMEs navigating the decision to join shared platforms for the first time.

> “ The decisive factor in whether data-sharing and collaborative intelligence could be achieved is not technology but trust.

4.3 Investment frameworks: de-risking the transition

“ A central challenge is the “viability” gap – the difference between upfront investments and level of risk-adjusted returns.

Intelligent infrastructure may require substantial upfront investment in assets across the DNA+ layers that generate returns over long time horizons. This investment profile creates a structural challenge: the actors who capture the benefits are often different from those who bear the costs. At the same time, uncertainty of returns is highest in the foundational DNA+ layers – the layers which are prerequisites for wider investment. A central challenge is the “viability” gap – the difference between upfront investments and level of risk-adjusted returns.

This mismatch between risk and reward limits capital deployment. Addressing it requires mechanisms that can distribute risk and align incentives across stakeholders, such as the following.

Public and private capital as complements

Neither public capital nor private capital alone can efficiently deliver the full stack. While public investment has traditionally anchored DNA+ layers with public-good characteristics, more cases show that private and public-private partnership models can equally deliver across these layers, particularly where long-term commercial returns justify the upfront commitment.

Public capital also plays a catalytic role when it is used to de-risk early-stage investment – for example, by offering sandboxes, supporting pilot deployments and funding shared platforms and standards. These actions reduce uncertainty by signalling policy commitment, clarifying regulatory direction and demonstrating technical feasibility, thereby crowding in private capital.

China’s 5G + Industrial Internet initiative profiled in Chapter 2 illustrates how public investment in 5G infrastructure reduced deployment risk, enabling private firms to invest in applications across manufacturing and supply chains.

Emerging market financing pathways as a structural imperative

In emerging and developing economies, additional constraints shape the investment landscape: domestic capital markets are often shallow, long-term institutional investors are less established and risk-transfer mechanisms are underdeveloped. In these contexts, development finance institutions (DFIs), blended finance models and instruments such as green bonds and official development assistance serve a critical catalytic function.

Multilateral co-investment platforms offer established mechanisms to bridge the viability gap and crowd in private capital where commercial returns alone are insufficient to justify upfront commitment.

Industrial clusters as the most tractable investment environments

Clusters’ concentrated geography, established relationships and shared economic interests can make governance more tractable and investment returns more attractive. Their scale is large enough to generate genuine network effects and small enough to remain manageable.

Critically, clusters enable a shift from optimizing individual assets to optimizing entire systems: the collective intelligence that emerges from shared data and coordinated decision-making across a cluster delivers efficiency gains that no single actor could achieve independently – as exemplified in the Net-Zero Basque Industrial Super Cluster (Spain) case study presented earlier.

Brownfield deployment as the dominant reality

Most intelligent infrastructure investment will not be in new facilities designed from scratch, but in the modernization of existing plants, ports, grids and buildings, where legacy systems, heterogeneous equipment and operational constraints cannot simply be set aside during an upgrade. This reality demands investment frameworks and deployment approaches that accommodate legacy integration: modular retrofitting pathways, public-private cost-sharing mechanisms for legacy conversion, and digital twin programmes that allow operators to model the impact of changes before implementing them.

4.4 Implementation pathways

Given this landscape, three implementation pathways have emerged globally, each suited to different combinations of starting position and strategic intent.

FIGURE 4 **Three possible implementation pathways**

PATHWAY 1

Simultaneous multi-layer deployment

This route involves investing across all DNA+ layers concurrently, enabling rapid transformation at scale. This approach – exemplified by China's Industrial Internet strategy, which simultaneously rolled out 5G connectivity, billions of industrial sensors[1] and over 240 cross-industry data platforms[2] – requires strong central coordination and substantial capital. It is most viable in contexts with mature policy institutions, available public and private financing and a strategic imperative for rapid national transformation.

PATHWAY 2

Priority-driven selective investment

This route focuses resources on the DNA+ layer that most constrains current performance. South Korea's 5G+ strategy prioritized the Network layer, establishing ubiquitous connectivity before incentivizing smart factory applications. India, by contrast, prioritized the AI layer through the unified logistics interface platform (ULIP), building a software integration backbone across 33 systems and seven ministries, thereby unlocking logistics efficiency without waiting for a complete overhaul of physical hardware.[3] This approach is particularly valuable for emerging economies or sectors with a specific binding constraint: identify the bottleneck, invest there first and build upwards.

PATHWAY 3

Phased layer-by-layer deployment

This route is the right approach for brownfield contexts with legacy systems and constrained resources. It begins by establishing foundational connectivity and device instrumentation, building the data assets and operational experience that justify subsequent investment in AI-driven orchestration and autonomous systems. This approach accepts a longer time horizon in exchange for lower upfront risk and a more gradual learning curve. It also allows governance arrangements to evolve alongside capability, reducing the institutional adjustment burden.

Sources: 1. Sinha, S. (2025). State of IoT 2025: Number of connected IoT devices growing 14% to 21.1 billion globally. *IoT Analytics.* https://iot-analytics.com/number-connected-iot-devices/; **2.** The State Council of the People's Republic of China. (2023). *5G, industrial internet to lift manufacturing.* http://english.www.gov.cn/news/202308/17/content_WS64dd6ffac6d0868f4e8dea19.html; **3.** Ministry of Commerce and Industry, Government of India. (2023). *ULIP to facilitate India's logistics sector with data-driven visibility and transparency.* https://www.pib.gov.in/PressReleasePage.aspx?PRID=1910298&reg=3&lang=2

Regardless of deployment pathways, two imperatives apply universally. AI-orchestration and cyber resilience must be integrated from the outset rather than added retrospectively. The convergence of IT and OT systems in intelligent infrastructure creates new attack surfaces; security designed as an overlay on top of an already-deployed system is structurally less effective than security embedded in the architecture from inception. This is not merely a technical consideration: it has governance, procurement, procurement and organizational dimensions that must be addressed at the planning stage, before capital is committed.

4.5 Talent capabilities

As intelligent infrastructure involves, workforce development should be treated as a dynamic, living component of deployment strategy rather than a precondition to be satisfied once and set aside.

Technology without the human capital to deploy and operate it does not deliver intelligent infrastructure; it delivers expensive underutilized assets. Across the Forum's consultations and workshop discussions, workforce capability emerged consistently as a deployment constraint that is underweighted relative to its actual impact.

The challenge is not simply a shortage of data scientists or AI engineers, but a fundamental shift in the organizational operating model. Intelligent infrastructure requires a workforce that is capable of working alongside AI systems and understands the boundaries of autonomous orchestration; it requires workers who can govern AI as an agent rather than a static tool and make decisions that span technical, operational and policy dimensions.

This requires a talent transition in three critical dimensions, outlined below.

Context-specific reskilling

Capability-building must be embedded within specific operational contexts. A port logistics operator, a power grid dispatcher and a manufacturing quality manager face distinct "intelligence gaps". Generic digital literacy is insufficient; instead, training must focus on domain-integrated AI governance, where operators learn to manage the interplay between layers, for instance between physical Devices and AI-driven Network optimization.

Augmenting institutional knowledge

The transition is most acute in "brownfield" environments where legacy operational knowledge is irreplaceable. Successful deployment models do not replace experienced workers but augment them. By integrating "human-in-the-loop" protocols into the AI orchestration tier, organizations can ensure that the nuanced reasoning of veteran engineers informs the training and refinement of machine learning models.

Cluster-level SME solutions

SMEs constitute the majority of industrial participants in most clusters, yet they lack the capital for internal capability-building. Policy interventions must focus on meso-industrial solutions: shared training hubs and public-private capability platforms hosted at the cluster level. These "centres of excellence" allow SMEs to access the high-level skills required to plug into intelligent supply chains without prohibitive upfront costs.

Building these capabilities is not a one-time intervention but an ongoing institutional commitment. As intelligent infrastructure involves, workforce development should be treated as a dynamic, living component of deployment strategy rather than a precondition to be satisfied once and set aside. Governments, industry leaders and educational institutions that invest in this capacity today are not simply training workers for current systems, they are taking the lead in building the organizational resilience required to adapt.

Conclusion

Prioritizing intelligent infrastructure allows companies, clusters, cities and countries to reimagine their roles in the global economy.

Evidence assembled in this report points to a consequential conclusion: intelligent infrastructure is becoming the foundational condition for national competitiveness. Countries, cities, clusters and companies that prioritize intelligent infrastructure are not simply upgrading their systems – they are reshaping how they participate in the global economy.

The right technology, in most cases, already exists. The barriers are institutional. Without coordination, systems risk becoming more complex but not more coherent. Without trust, data remains fragmented and its potential unrealized. Without investment in people, intelligence remains underutilized. The cost of inaction will compound.

This report goes beyond framing the concept of intelligent infrastructure; it aims to support the transition from insight to implementation. The World Economic Forum will work with stakeholders across the 4Cs ecosystem: convening multi-stakeholder dialogue to align standards and accelerate innovation adoption, facilitating knowledge exchange between leading and emerging economies and supporting the development of implementation pathways. We invite policy-makers and businesses to join us in this effort.

Intelligent infrastructure may be remembered as a layer added to the economy. Or it may come to define the backbone of how economies function. Choices made today will determine the path it takes.

Contributors

Lead authors

Chiara Barbeschi
Specialist, Technology & Innovation, Centre for Cybersecurity, World Economic Forum

Filipe Beato
Manager, Technology & Innovation, Centre for Cybersecurity, World Economic Forum

Devendra Jain
Lead, Frontier Technologies for Operations, Centre for Advanced Manufacturing and Supply Chains, World Economic Forum

Qi Pan
Project Fellow, Centre for Advanced Manufacturing and Supply Chains, World Economic Forum

Adair Smith
Community and Initiatives Lead, Centre for Urban Transformation, World Economic Forum

Federico Torti
Head, Technology and Innovation, Centre for Advanced Manufacturing and Supply Chains, World Economic Forum

Irene Varoli
Lead, Transitioning Industrial Clusters, Centre for Energy and Materials, World Economic Forum

Sakshi Vohra
Specialist, Strategy and Operations, Centre for the Fourth Industrial Revolution India, World Economic Forum

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Manuel Romero Agudo
Cybersecurity Architect, Repsol

Abdulaziz Al-Ali
Managing Director, Centre for the Fourth Industrial Revolution, Qatar

Abdullah Saleh M Alharbi
Project Fellow, Global Lighthouse Network, World Economic Forum

Eid Alharbi
President of Connectivity, Aramco Digital

Daniel Alvarez
Cybersecurity Program Director, Hitachi Energy

Arvind Anantharaman
Operating Partner, MGX Fund Management

Maria Basso
Head, AI Applications and Impact, Centre for AI Excellence, World Economic Forum

Dimitris Christopoulos
Director, Centre for Networks and Enterprise Excellence (CNEE), Heriot-Watt University

Maximilian Dauer
Project Manager, Kopernikus ENSURE, Siemens

Suketu Gandhi
Senior Partner and Chair, Strategic Operations, Kearney

Waleed Gowharji
General Manager, Projects and Initiatives, Centre for the Fourth Industrial Revolution, Saudi Arabia

Andreas Groeger
Chief Technology Officer, Industrial Automation, Schneider Electric

Glenn Gu
Senior Director, Product and Development, Envision Energy

Rana Hajirasouli
Founder and Chief Executive Officer, The Surpluss

Ryan Hardin
Head of Unit, Energy Transition, MYCentre4IR

Nigel J Jenvey
Vice President CCUS and H_2 Project Development, Baker Hughes

Filippos Kaponis
Strategy Principal Director, Accenture

René Kerkmeester
Global Vice President, Integrated Power, Capgemini

Vaibs Kumar
Senior Vice President, Technology, Industrial Financial Systems (IFS)

Sophie Miremadi
Vice-President, Global Government Affairs and Public Policy, AVEVA Group

Madav Murali Mohan
Senior Director, Business Development, Qualcomm

Mark Nagel
Vice President, Product Platforms, Baker Hughes

Quyen Nguyen
Senior Adviser, Centre for the Fourth Industrial Revolution, Viet Nam

Charles Pacini
Manager, Transforming Industrial Ecosystems, World Economic Forum

Geoffrey Parker
Professor, Thayer School of Engineering, Dartmouth College, Director of the Irving Institute for Energy and Society

Kumar Patchigolla
Professor of Decarbonization of Industrial Clusters, Teesside University

David Prats
Vice President, Data Risk and Security, Schneider Electric

Yuriy Shaulko
Chief Technical Officer, Global Cloud Security, Trafigura Group

Victor Guang Shi
Supply Chain Resilience Lead, Advanced Manufacturing Research Centre, University of Sheffield

Jörgen Sandström
Head, Transforming Industrial Ecosystems, World Economic Forum

Jonne Soininen
Strategic Lead and Sponsor of Nokia Technology Vision, Nokia Corporation

Andrew Staines
Assistant Director General, World Intellectual Property Organization

Andrew Swart
Global Energy, Resources and Industrials Industry Leader, Deloitte

Bart Valkhof
Head, Information and Communication Technology Industry, World Economic Forum

María San Salvador del Valle
Strategic Initiatives, Basque Business Development Agency (SPRI)

Gary Wong
Global Head, Infrastructure, AVEVA Group

Debbie Yu
Co-Founder and President, ISEE

Production

Laurence Denmark
Creative Director, Studio Miko

Charlotte Ivany
Designer, Studio Miko

Jonathan Walter
Editor

World Economic Forum Public Engagement

Maxwell Hall
Creative Editorial Lead

Floris Landi
Design Lead

Gayle Markovitz
Head, Written and Audio Content

Sybile Penhirin
Head, Video and Design

Endnotes

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   - Semantic interoperability: systems do not just share data but understand the meaning of that data in the same way (e.g. the same system sends "temperature = 100" and the system knows this is 100°C and above a safe threshold).
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World Economic Forum
91–93 route de la Capite
CH-1223 Cologny/Geneva
Switzerland

Tel.: +41 (0) 22 869 1212
Fax: +41 (0) 22 786 2744
contact@weforum.org
www.weforum.org